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Vegetation survey and hydrochemical characterization of newly discovered mountain wetlands in the Madonie and Nebrodi mountains (Sicily)

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Abstract

The wetland vegetation of two unexplored mountain localities of Sicily was surveyed. A total of 14 wetland sites (springs, peaty springs, temporary ponds) are newly described. Vegetation plots and associated hydrochemical variables were surveyed in each site. The classification of the vegetation relevés led to the description of ten new plant communities, along with records of additional syntaxa already known from other areas of Sicily and southern Italy. All the identified plant communities and associations belong to the *Dactylorhizo sacciferae-Juncion striati* (*Molinio-Arrhenatheretea*) and the *Alopecuro-Glycerion spicatae* (*Phragmito-Magnocaricetea*) alliances. Nomenclatural revisions are proposed for certain syntaxa. The composition and structure of the described plant communities are analyzed and discussed in comparison with related communities from other European regions.

Keywords

Mediterranean vegetation, peatlands, springs, syntaxonomy, temporary ponds, vegetation classification, wetland flora

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Introduction

Wetlands are an important element in defining the Mediterranean Basin as a biodiversity hotspot. The composition and structure of wetland vegetation are influenced by particular climatic conditions, which vary significantly from sea level to high mountain areas and, consequently, affect the hydrological regime (Chappuis et al. 2014).

Among the Mediterranean regions, Sicily stands out for the extreme heterogeneity of its wetland biotopes. In particular, mountain wetlands of the island hold important biogeographic value. For example, among minerogenous environments, such as peat bogs, the *Sphagnum*-transitional mires of the Madonie mountains are the southernmost in Europe (Raimondo and Dia 1978; Bracco et al. 2004). Wet meadows and springs host hygrophilous plant communities that are endemic to southern Italy (Brullo and Grillo 1978).

Besides, ombrogenous environments, such as temporary ponds, have a water balance influenced by the alternation between the rainy season and the dry summer period, which leads to seasonal fluctuations in water levels. This factor has driven the adaptation of aquatic plant communities endemic to the island (Brullo et al. 1994).

Recent studies highlighted a significant knowledge gap with respect to the distribution and conservation of plant species in Mediterranean wetlands (Fois et al. 2024). Unlike the flora, which in most Sicilian mountains has been well studied (Gianguzzi 1999; Raimondo 2004; Raimondo et al. 2005), the state of knowledge of the vegetation of mountain wetlands is still scarce or outdated in many areas of the island (Bajona et al. 2025). Consequently, recent surveys in previously little-known areas have led to the discovery and description of new plant communities (Raimondo et al. 2021a, b; Caldarella et al. 2021; Sciandrello et al. 2021).

In this context, the present survey arises from the need to investigate the vegetation of wetlands (springs, peaty springs, and temporary ponds) in two unexplored mountain localities of Sicily, located in the Madonie and Nebrodi mountain sectors.

Materials and methods

Area of study

The vegetation of 14 wetland sites located in two mountainous sectors, *i.e.*, the Madonie and Nebrodi mountains (Fig. 1), was surveyed. In the Madonie, within the municipality of San Mauro Castelverde (province of Palermo), six sites, including springs and peat bogs, were surveyed, while in the Nebrodi, within the municipality of Mistretta (province of Messina), eight sites were investigated, including three temporary ponds and five springs and peaty springs (Table 1).

The Madonie sites lie between the valleys of the Pollina River, to the west, and the Tusa stream, to the east, a few kilometers above the town of Tusa (province of Messina). The sites are characterized by springs and peaty springs developing in flat areas at the foothills of Cozzo Signorina (1124 m a.s.l.) and Pizzo Voturo (1223 m a.s.l.). The

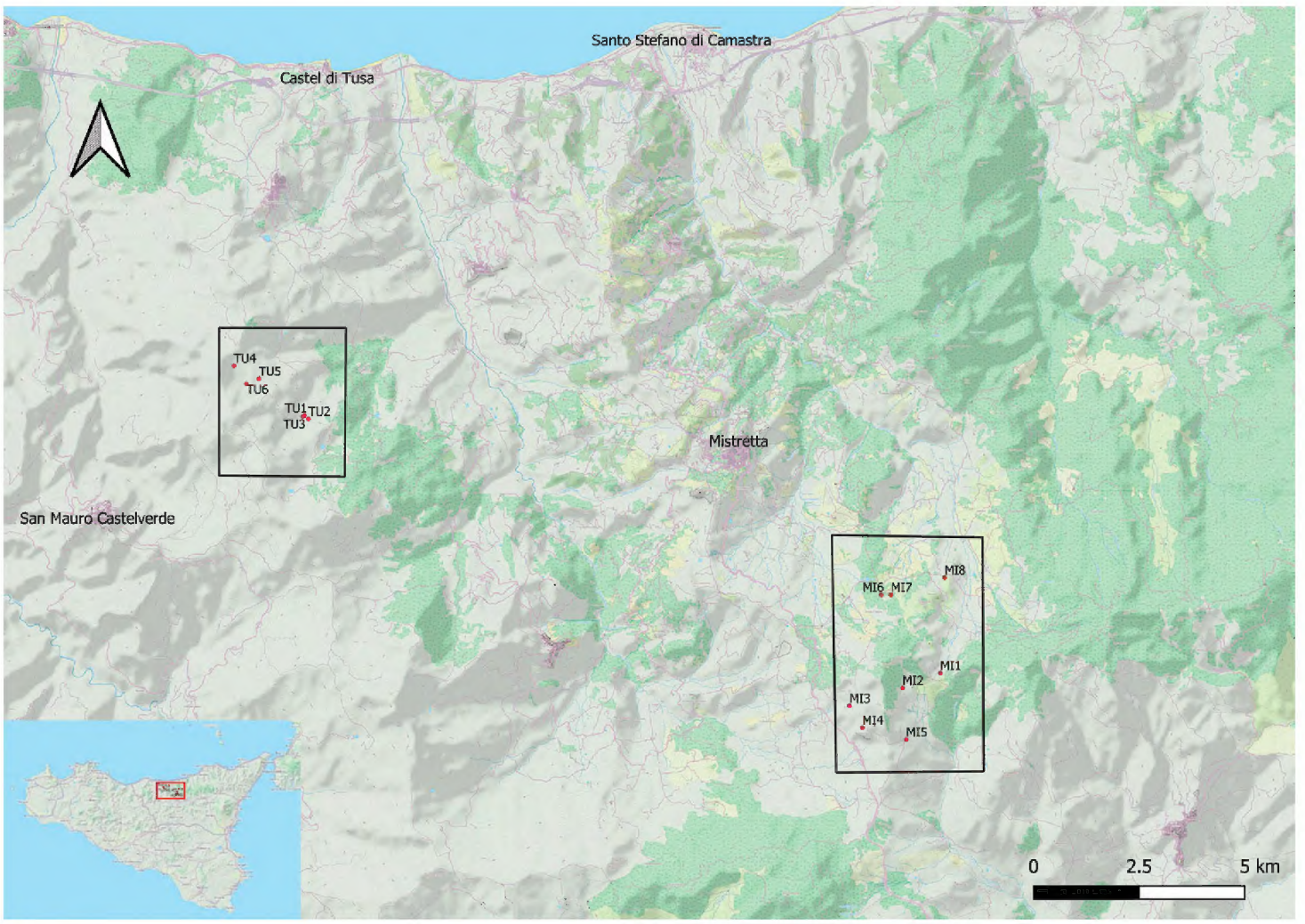

Figure 1. Distribution of sites along the two mountainous sectors of Madonie (TU1-TU6) and Nebrodi (MI1-MI8). The figure is based on OSM TF Landscape map (Maps Thunderforest).

Table 1. Geographical and morphological information about the study sites.

Site name	GPS coordinates	Province	Municipality	Altitude (m a.s.l.)	Area (m^2)	Wetland type
TU1	37°56'09.08"N, 14°14'40.58"E	Palermo	San Mauro Castelverde	802	562	Peaty spring
TU2	37°56'06.58"N, 14°14'44.41"E	Palermo	San Mauro Castelverde	805	659	Spring
TU3	37°56'08.49"N, 14°14'39.00"E	Palermo	San Mauro Castelverde	810	439	Spring
TU4	37°56'47.19"N, 14°13'32.56"E	Palermo	San Mauro Castelverde	965	862	Peaty spring
TU5	37°56'37.27"N, 14°13'56.72"E	Palermo	San Mauro Castelverde	918	290	Peaty spring
TU6	37°56'33.35"N, 14°13'44.56"E	Messina	Mistretta	975	201	Spring
MI1	37°52'52.64"N, 14°24'55.12"E	Messina	Mistretta	1293	265	Temporary pond
MI2	37°52'41.25"N, 14°24'18.70"E	Messina	Mistretta	1317	800	Spring
MI3	37°52'27.68"N, 14°23'27.41"E	Messina	Mistretta	1215	3076	Spring
MI4	37°52'11.06"N, 14°23'39.79"E	Messina	Mistretta	1225	830	Temporary pond
MI5	37°52'01.91"N, 14°24'22.30"E	Messina	Mistretta	1190	682	Silted-up pond
MI6	37°53'52.59"N, 14°23'57.93"E	Messina	Mistretta	1073	1000	Spring
MI7	37°53'52.57"N, 14°24'07.51"E	Messina	Mistretta	1045	588	Peaty spring
MI8	37°54'05.73"N, 14°24'59.28"E	Messina	Mistretta	993	607	Temporary pond

geological formations of the area consist of the "Flysh Numidico" (Upper Oligocene–Lower Miocene), which includes dark grey mudstones and brown clays with indistinct stratification, interspersed with thick beds of yellowish quartzarenites (ISPRA 2011).

This geological formation is in contact with the "Marne di Castelbuono" (Lower Miocene), consisting of dark grey marly clays and micaceous quartz siltstones in thin layers, with frequent interspersed marl megabeds.

The sites investigated in the Nebrodi mountains are distributed on the northern (MI6–MI8) and southern (MI1–MI5) slopes of Monte Castelli (1,566 m a.s.l.), where the geological formations consist of Upper Miocene (Tortonian) deposits of grey sands and clayey sands with rare interspersed marly outcrops (Servizio Geologico d'Italia 1972).

The geological characteristics of the area play a key role in wetland development. In particular, fine-grained arenaceous substrates limit rainwater percolation and promote the retention of groundwater, as observed in wetland sites in the Apennines (Di Pietro et al. 2024).

Vegetation survey

The vegetation survey was carried out in June and July 2025, corresponding to the phenology of most species, through visual estimation of the percentage cover of vascular plants and bryophytes. Since pH and electrical conductivity (EC) of the water were also measured in each plot, a plot size of 1 m^2 was selected. Although Chytrý and Otýpková (2003) recommend a 4-m^2 size for most types of aquatic vegetation, a smaller area was preferred in order to obtain a more precise and accurate relationship between vegetation and measured abiotic variables. Water pH and electrical conductivity (EC, µS/cm) were measured in the field using a portable XS pH 7 Vio pH-meter (Electrode 201 T) and a portable XS COND 7 Vio conductivity meter (Cell 2301 T), respectively. In each plot the topography of the stands (flat/depression) was recorded too. Plots were randomly distributed within areas where vegetation was physiognomically homogeneous with isotropic environmental conditions (slope, topography, water table).

Plant species were identified following "Flora d'Italia" (Pignatti et al. 2017–2019) and "Flora Iberica" (Castroviejo 1986–2012). The nomenclature of native flora is referred to Bartolucci et al. (2024) while for the nomenclature of alien species we used the publication of Galasso et al. (2024). Bryophyte nomenclature follows Aleffi et al. (2023). Voucher specimens are deposited in the herbarium of the Department of Agricultural, Food, and Forest Sciences of the University of Palermo (SAF).

Data analysis

All data analyses were conducted using R software (version 4.4.0; R Core Team 2024), with Vegan Community Ecology Package (Oksanen et al. 2025), JUICE software (version 7.0.102), and CANOCO 5 (Šmilauer and Lepš 2014).

A preliminary ordination of the compositional data (species abudance-cover values) of the relevés, with environmental variables (pH, EC, topography) considered as predictors, was performed in CANOCO 5. Compositional data and EC values were log-transformed before the analysis. Since the compositional data have a gradient that

is 7.4 SD units long, a constrained unimodal ordination method (CCA) was used. Then, a variation partitioning test was performed on the model to quantify the variability among communities as driven by environmental variables.

Subsequently, to test if the groups distinguished by the ordination model show floristic distinctiveness, species fidelity to groups (*Phi* coefficient, Chytrý et al. 2002) was calculated. The significance of the coefficient was assessed using Fisher's exact test in JUICE. Each species was considered significantly associated with a group if it showed a fidelity value > 20 with a p-value < 0.01 in Fisher's exact test (Gennai et al. 2021).

To highlight potential differences in biological forms between the ordination groups, biological forms from "Flora d'Italia" (Pignatti 2005) were assigned in a simplified manner to each plant species, excluding bryophytes. Biological forms are abbreviated as follows: CH = reptant chamephyte; G = rhizomatous/bulbous geophyte; H = scapose/caespitose/biennial hemicryptophyte; I RAD = rooted hydrophyte; NP = nano-phanerophyte; P = phanerophyte; T = scapose/caespitose/reptant therophyte.

Moreover, a cluster analysis was applied to detect thiner similarity in relevés composition and to separate homogeneous groups of relevés clusters. The data matrix (species cover × plots) was initially normalized, and a distance matrix based on the Bray-Curtis distance was calculated. This matrix was then analyzed through the Unweighted Pair Group Method with Arithmetic Mean Clustering (UPGMA) method.

This was followed by the syntaxonomic classification of the clusters of relevés. Species assignment to syntaxa was based on European-level references (Chytrý et al. 2024) and on publications dealing with local sicilian studies (Brullo and Grillo 1978; Brullo et al. 1994; Cambria 2020; Brullo et al. 2001). In particular, local publications were chosen in order to assign syntaxonomical rank to species, since these are focussed on a similar ecological context as this study. For species not found in local publications, the European-level references were followed. The nomenclature of higher-rank syntaxa follows Mucina et al. (2016). Finally, the nomenclature revisions of syntaxa follow the rules of ICPN 4th edition (Theurillat et al. 2020).

Results and discussion

Vegetation survey

A total of 50 vegetation 1-m^2 plots were surveyed across the 14 wetland sites. The vegetation survey focused on some temporary ponds or wet meadows, springs (muddy or peaty, rich in silt-clay content) and peaty springs with perennial water saturation due to the presence of a shallow water table. An initial visual interpretation of the vegetation allowed the identification of communities based on physiognomy, *i.e.*, considering the distinctiveness of microenvironmental conditions (degree of hydromorphism, substrate type) and vegetation properties (dominant floristic composition, herbaceous layer height), (Cristea et al. 2015). Using this approach, seven physiognomic types were initially distinguished:

- flooded peaty meadows with dense vegetation cover (>90%) dominated by *Juncus articulatus* L., *Carex* sp. pl., *Cyperus longus* L., *Glyceria* sp. pl., often characterized by a moss layer;
- wet meadows with silty or peaty substrate dominated by tall rushes (*Juncus effusus* L., *J. inflexus* L.);
- wet grasslands dominated by *Deschampsia cespitosa* (L.) P.Beauv.;
- flooded meadows on silty or peaty substrate dominated by *Limniris pseudacorus* (L.) Fuss;
- flooded meadows on silty or peaty substrate dominated by *Eleocharis palustris* (L.) Roem. & Schult.;
- shady pools with silty or peaty substrate dominated by *Ranunculus omiophyllus* Ten. and *Callitriche stagnalis* Scop.;
- shallow temporary ponds with silty bottoms and aquatic phytocenoses.

Classification and description of plant communities

The CCA ordination model of the 50 relevés, based on pH, EC, and topography, explains 19.74 % of the total compositional data' variation (total variation=7.58). In particular, the first axis accounts for most of the variation (9.28%), the second axis for 5.53% and the third axis only for 4.93% (Table 2).

A variation partitioning test was performed on the model to quantify the amount of community variability expressed by the environmental variables; hydrochemical variables pH and EC were tested independently from topography. Results show that all environmental variables play a significant role in affecting community variability (p-value<0.001 in the Monte Carlo significance test). Using the same test, we quantified the amount of community variation explained by each group of variables (Table 3).

Table 2. Statistic values of CCA ordination model.

	Axis 1	Axis 2	Axis 3
Explained variation (cumulative)	9.28	14.81	19.74
Explained fitted variation (cumulative)	47.03	75.03	100.00
Permutation Test Results			
On First Axis	pseudo-F=1.6, p<0.001		
On All Axes	pseudo-F=3.8, p<0.001		

Table 3. Statistical values of the variation partitioning test.

	Variation (adj)	% of Explained	% of All	DF	Mean Square
Topography	0.5546	50.5	7.3	1	0.66415
pH+EC	0.5495	50	7.3	2	0.40136
Overlap	-0.005	-0.5	-0.1	–	–
Total Explained	10.992	100	14.5	3	0.49859
All Variation	7.577	–	100	49	–

Topography accounts for 7.3% of the variation, pH+EC for 7.3% with no correlation between the two groups of variables since the effects of topography and of pH+EC do not overlap in their explanatory power (the overlap size is estimated as -0.1%).

As showed in the ordination graph (Fig. 2), the environmental variable topography is well described by the first axis, while pH and EC are related to the second

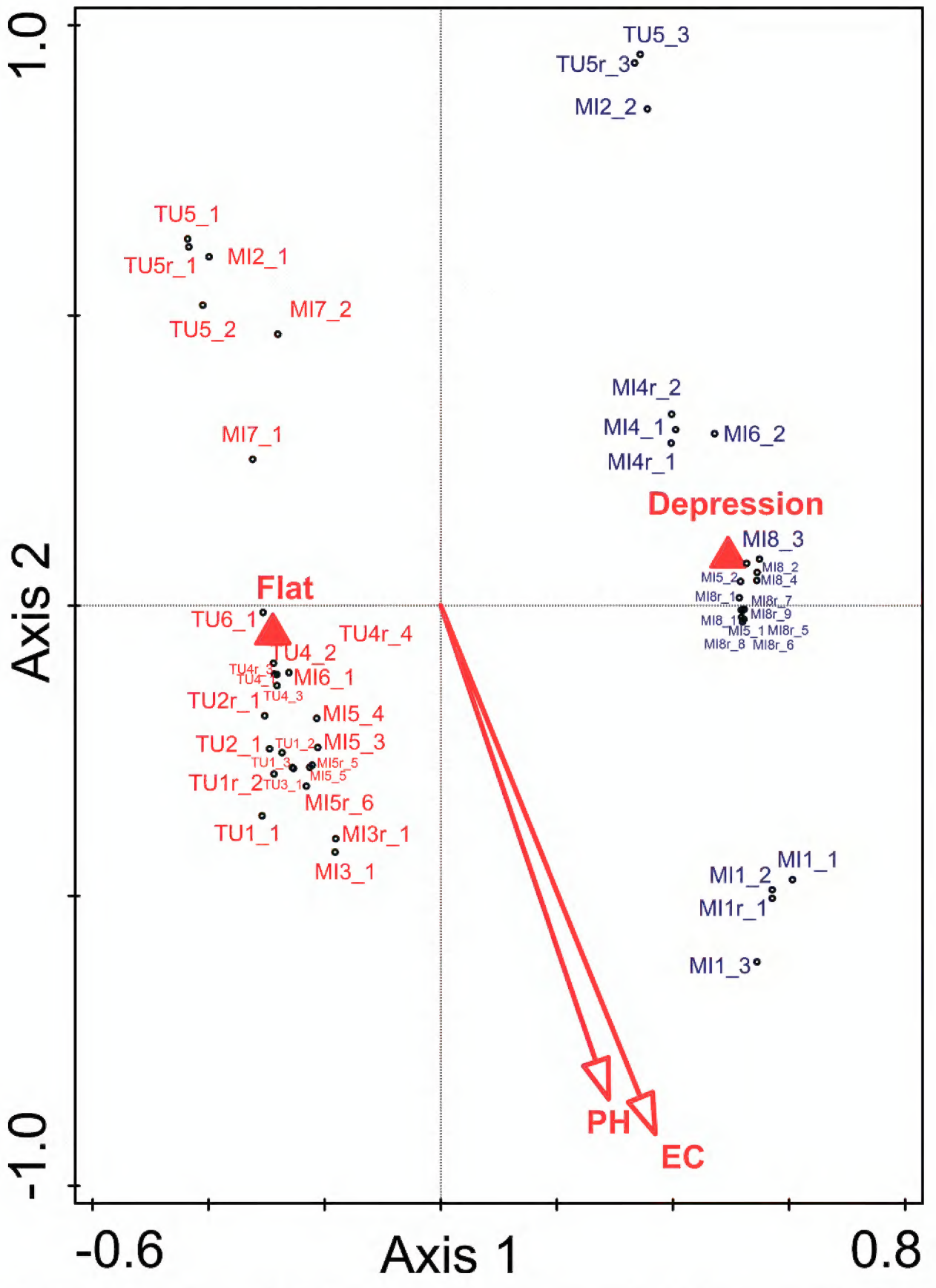

Figure 2. CCA ordination graph of relevés based on environmental variables Topography (Flat/Depression), pH, EC. The two groups of relevés GROUP_1 (red plot labels) and GROUP_2 (blue plot labels) are clearly separated on the basis of species composition and environmental variable. Plots with flat topography occur in springs and wet meadows, while those with depression topography are found in temporary ponds and shady pools.

axis. The positition of plots in the graph distinguishes communities that occur on flat stands (left side, GROUP_1) from those related to stands in depressions (right side, GROUP_2). It is clear that topography, among those measured, is the factor that has the greatest effect in shaping plant community composition since it accounts also for differences in the water regime. In fact, flat stands are springs fed by groundwater or silted-up ponds, while depression stands are temporary ponds and shady pools mostly fed by rainwater. Consequently, flat stands are permanently or semi-permanently water-saturated during the vegetation's growth season, differently from depression stands that become dry during most of the summer, while storing a larger water volume from winter to early summer.

The plots of the two groups have also edaphic differences. In particular, GROUP_1 includes stands with hygrophilous vegetation developing on peaty and peaty-clayey substrates, while GROUP_2 includes plots surveyed in shallow temporary ponds (MI8, MI4, MI1), shady pools (TU5_3, TU5r_3, MI2_2, MI6_2) and in flooded meadows (MI5) with silty or muddy substrate.

Plots occuring in depression stands are also differentiated by hydrochemical values, *i.e.*, those located at the top-right side of the graph (TU5_3, TU5r_3, MI2_2) have lower pH and EC than those located at the bottom-right. Top-right and bottom-right plots differ for biotope type too, namely shady temporary pools for top-right plots and temporary ponds for bottom-right ones.

Moreover, observing the differences in the frequency of biological forms for each group, although both are dominated by hemicryptophytes, hydrophytes are much more frequent in GROUP_2 (36%) compared to GROUP_1 (4,5%) (Fig. 3). The frequency of therophytes is relatively low in both groups, with a higher value in GROUP_1, reflecting the more terrestrial character of its communities.

GROUP_1 includes communities richer in species than GROUP_2 (species richness of GROUP_1 relevés is 65, while in GROUP_2 it is 25), probably because the respective biotopes offer a wider spectrum of ecological niches and are in close contact with xeric grasslands, unlike GROUP_2, where markedly marshy conditions and seasonal water fluctuations restrict recruitment to stenoecious species.

Regarding vegetation composition, the analysis of species significantly associated with each Group shows that GROUP_1 relevés are distinguished from GROUP_2 by the presence of many species characteristic of the *Molinio-Arrhenatheretea* R.Tx.1937 class, such as *Trifolium repens* L., *Poa trivialis* L., *Cynosurus cristatus* L., *Bromus hordeaceus* L., *Deschampsia cespitosa* (L.) P.Beauv., *Phleum pratense* L. (*phi*>20) and, in particular, of the alliance *Holoschoenetalia* Br.-Bl. ex Tchou 1948, including *Juncus articulatus* L., *Holcus lanatus* L., *Lythrum junceum* Banks & Sol., *Calliergonella cuspidata* (Hedw.) Loeske, *Cyperus longus* L., *Cirsium creticum* subsp. *triumfettii* (Lacaita) K.Werner, *Polypogon viridis* (Gouan) Breistr., *Galium debile* Desv., *Juncus effusus* L., *J. inflexus* L., *Rumex conglomeratus* Murray (*phi*>20) (Suppl. material 1). Moreover, a few *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941 species (*Mentha aquatica* L., *Helosciadium nodiflorum* (L.) W.D.J.Koch, *Carex acutiformis* Ehrh., *Veronica anagallis-aquatica* L.) are associated with this group.

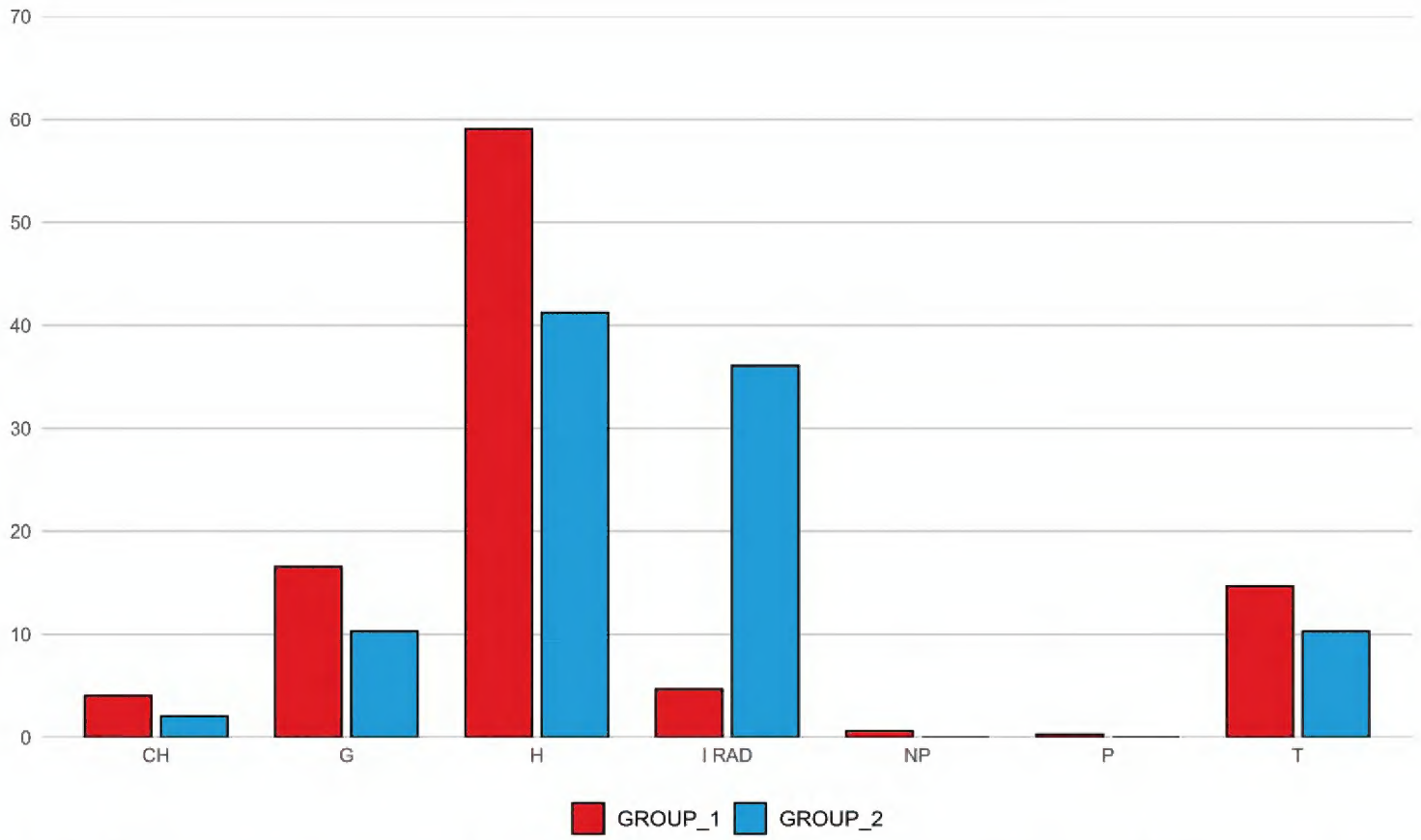

Figure 3. Relative frequency of biological forms of vascular plants in each Group (CH = reptant chamephyte; G = rhizomatous/bulbous geophyte; H = scapose/caespitose/biennial hemicryptophyte; I RAD = rooted hydrophyte; NP = nano-phanerophyte; P = phanerophyte; T = scapose/caespitose/reptant therophyte). The two groups distinguish terrestrial from more markedly acquatic communities.

On the contrary, GROUP_2 is characterized by few species significantly associated with it, belonging to more than one class of aquatic communities, such as *Helosciadium inundatum* (L.) W.D.J.Koch and *Callitriche stagnalis* Scop. (Char. *Littorelletea uniflorae* Br.-Bl. et Tx. ex Westhoff et al. 1946), *Oenanthe aquatica* (L.) Poir., and *Glyceria spicata* Guss., *Peplis portula* L. that are diagnostic species of the *Oenanthetalia aquaticae* Hejný ex Balátová-Tuláčková et al. 1993 and of the *Alopecuro-Glycerion spicatae* S. Brullo et al. 1994, Cl. *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941, respectively.

The communities of GROUP_1 and GROUP_2 were, therefore, assigned to the alliances *Dactylorhizo-Juncion striati* Brullo & Grillo, 1978 (*Holoschoenetalia* Br.-Bl. ex Tchou 1948, *Molinio-Arrhenatheretea* R.Tx. 1937) and *Alopecuro-Glycerion spicatae* S. Brullo et al. 1994 (*Oenanthetalia aquaticae* Hejný ex Balátová-Tuláčková et al. 1993, *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941), respectively (Table 4, Suppl. material 1).

The alliance *Dactylorhizo-Juncion striati*, originally described by Brullo and Grillo (1978) from the eastern sector of the Nebrodi mountains, characterizes the mountain humid swards of Calabria and Sicily, which differ from central European vicariant communities by the presence of several thermophilous species acting as differential species (Brullo and Grillo 1978).

However, this alliance and its type association (Holotypus: *Dactylorizo-Juncetum effusi* Brullo & Grillo, 1978), originally reported *Dactylorhiza elata* var. *munbyana* (Boiss. & Reut.) Soó ≡ *Orchis munbyana* Boiss. & Reut. = *Dactylorhiza elata* (Poir.) Soó (according to "Plants of the World Online" 2025) as a characteristic species; this

Table 4. Structured syntaxonomic table showing floristic differentiation between GROUP_1 (No. of plots = 27) and GROUP_2 (No. of plots = 23) on the basis of fidelity and frequency of species.

	Phi **GROUP_1**	**Frequency GROUP_1**	***Phi*** **GROUP_2**	**Frequency GROUP_2**
Char. *DACTYLORHIZO SACCIFERAE-JUNCION STRIATI*				
Dactylorhiza maculata subsp. *saccifera* (Brongn.) Diklić	44.7	9	0	0
Carex otrubae Podp.	*35.4*	6	0	0
Ranunculus lanuginosus L.	*13.7*	1	0	0
Char. *HOLOSCHOENETALIA*				
Juncus articulatus L.	*59*	16	0	1
Holcus lanatus L.	*50.6*	11	0	0
Lythrum junceum Banks & Sol.	*50.6*	11	0	0
Calliergonella cuspidata (Hedw.) Loeske	*38.6*	7	0	0
Cyperus longus L.	*38.6*	7	0	0
Cirsium creticum subsp. *triumfettii* (Lacaita) K.Werner	*35.4*	6	0	0
Galium debile Desv.	*34.7*	12	0	3
Rumex conglomeratus Murray	*34.7*	12	0	3
Juncus effusus L.	*32.8*	13	0	4
Polypogon viridis (Gouan) Breistr.	*31.9*	5	0	0
Juncus inflexus L.	*24.3*	3	0	0
Carex distans L.	*13.7*	1	0	0
Char. *MOLINIO-ARRHENATHERETEA*				
Poa trivialis L.	*67.8*	17	0	0
Cynosurus cristatus L.	*56.3*	13	0	0
Trifolium repens L.	*43.7*	13	0	2
Bromus hordeaceus L.	*41.7*	8	0	0
Deschampsia cespitosa (L.) P.Beauv.	*28.3*	4	0	0
Phleum pratense L.	*24.3*	3	0	0
Lotus rectus L.	*19.6*	2	0	0
Anthoxanthum odoratum L.	*13.7*	1	0	0
Poa pratensis L.	*13.7*	1	0	0
Hypericum tetrapterum Fr.	*13.7*	1	0	0
Oenanthe pimpinelloides L.	*13.7*	1	0	0
Ranunculus sardous Crantz	*12.7*	3	0	1
Juncus fontanesii J.Gay	*4*	3	0	2
Char. *ALOPECURO-GLYCERION SPICATAE*				
Glyceria spicata Guss.	*0*	2	52.7	13
Peplis portula L.	*0*	0	21.3	2
Char. *OENANTHETALIA AQUATICAE*				0
Oenanthe aquatica (L.) Poir.	*0*	0	42.4	7
Char. *PHRAGMITO-MAGNOCARICETEA*				0
Mentha aquatica L.	*55.9*	15	0	1
Helosciadium nodiflorum (L.) W.D.J.Koch	*49.8*	13	0	1
Nasturtium officinale W.T.Aiton	*38.6*	7	0	0
Veronica anagallis-aquatica L.	*35.4*	6	0	0
Carex acutiformis Ehrh.	*28.3*	4	0	0
Limniris pseudacorus (L.) Fuss	*28.3*	4	0	0

	Phi GROUP_1	Frequency GROUP_1	*Phi* GROUP_2	Frequency GROUP_2
Oenanthe fistulosa L.	*4*	8	0	6
Ranunculus ophioglossifolius Vill.	*0*	1	16.9	3
Glyceria notata Chevall.	*1*	12	0	10
Eleocharis palustris (L.) Roem. & Schult.	*0*	7	5	7
Char. *ISOETO-NANOJUNCETEA*				
Isolepis cernua (Vahl) Roem. & Schult.	*50.6*	11	0	0
Juncus bufonius L.	*22.3*	5	0	1
Samolus valerandi L.	*13.7*	1	0	0
Ranunculus muricatus L.	*12.7*	3	0	1
Myosotis sicula Guss.	*0*	0	14.9	1
Mentha pulegium L.	*0*	1	39.4	8
Char. *LITTORELLETEA UNIFLORAE*		0		
Helosciadium inundatum (L.) W.D.J.Koch	*0*	0	42.4	7
Callitriche stagnalis Scop.	*0*	1	22.3	4
Char. *MONTIO-CARDAMINETEA*				
Ranunculus fontanus C.Presl	*19.6*	2	0	0
Carex remota L.	*19.6*	2	0	0
Ranunculus omiophyllus Ten.	*0*	0	30.9	4
Companions		0		
Geranium dissectum L.	*35.4*	6	0	0
Lolium arundinaceum (Schreb.) Darbysh.	*28.3*	4	0	0
Carex punctata Gaudin	*24.3*	3	0	0
Cirsium vulgare (Savi) Ten.	*24.3*	3	0	0
Rubus ulmifolius Schott	*19.6*	2	0	0
Trifolium glomeratum L.	*19.6*	2	0	0
Equisetum telmateia Ehrh.	*19.6*	2	0	0
Brachypodium distachyon (L.) P.Beauv.	*13.7*	1	0	0
Anisantha sterilis (L.) Nevski	*13.7*	1	0	0
Festuca myuros L.	*13.7*	1	0	0
Lysimachia arvensis (L.) U.Manns & Anderb.	*13.7*	1	0	0
Anacamptis laxiflora (Lam.) R.M.Bateman, Pridgeon & M.W.Chase	*13.7*	1	0	0
Panicum miliaceum L.	*13.7*	1	0	0
Bellardia viscosa (L.) Fisch. & C.A.Mey.	*13.7*	1	0	0
Philonotis fontana (Hedw.) Brid.	*13.7*	1	0	0
Prunus spinosa L.	*13.7*	1	0	0
Sonchus asper (L.) Hill	*13.7*	1	0	0
Trifolium campestre Schreb.	*13.7*	1	0	0
Aira caryophyllea L.	*0*	0	14.9	1
Ranunculus peltatus Schrank	*0*	0	30.9	4

species is distributed in France, Spain, Morocco, Algeria, and Tunisia (Vela et al. 2017) but is absent in Italy (Bartolucci et al. 2024), where instead *Dactylorhiza elata* subsp. *sesquipedalis* (Willd.) Soó is limited to Sardinia (Fenu et al. 2010; Bartolucci et al.

2024). Therefore, according to Article 43 of ICPN 4th edition (Theurillat et al. 2020), the names of the two syntaxa are incorrect due to misidentification of their characteristc species assigned in the protologue (Brullo and Grillo 1978). As shown by the relevés presented in this work (Suppl. material 1), and as observed by other authors (Brullo et al. 2001; Cambria 2020), the true characteristic species of *Dactylorhizo-Juncion striati* Brullo & Grillo, 1978 is *Dactylorhiza maculata* subsp. *saccifera* (Brongn.) Diklić. Thus, according to Article 43, we propose the correction of the above syntaxa names: *Dactylorhizo sacciferae-Juncion striati* Brullo & Grillo, 1978 corr. Bajona 2025; *Dactylorhizo sacciferae-Juncetum effusi* Brullo & Grillo, 1978 corr. Bajona 2025.

Besides, the alliance *Alopecuro-Glycerion spicatae* S. Brullo et al., 1994, endemic to Sicily, includes well-differentiated upland marshy communities physiognomically dominated by rooting hydrophytes (*Glyceria spicata*, *Alopecurus aequalis* Sobol., *Peplis portula* L.) and scapose hemicryptophytes (*Oenanthe fistulosa* L.), which tend to form more or less dense mats with only the terminal vegetative and flowering parts emerging. This alliance was described by Brullo et al. (1994) for shallow ponds subject to summer drying, with silty or muddy bottoms, in the Nebrodi mountains, originally classified within the *Potamogetonetea* Klika in Klika et Novák 1941. However, Mucina et al. (2016) rejected this original placement due to the dominance of *Phragmito-Magnocaricetea* species that characterize the stands, and thus it has been classified within the order *Oenanthetalia aquaticae* (*Phragmito-Magnocaricetea*). Our relevés also lack *Potamogetonetea* species (Suppl. material 1), thus confirming the classification of Mucina et al. (2016). Communities of this alliance have been recently described outside the Nebrodi mountains, in the hinterland of western Sicily (Gianguzzi et al. 2024).

Cluster analysis of the relevés matrix generated a dendrogram in which the groups of relevés are separated for floristic similarities. Through coenologicical interpretation based on omogeneity of floristic composition, dominant species and environmental factors, the following classification is proposed (cluster dendrogram in Suppl. material 2).

A brief description of the communities, distinguished based on dominant species shaping their physiognomy, is presented below.

GROUP_1. *Molinio-Arrhenatheretea* Tx., 1937; *Holoschoenetalia* Br.-Bl. ex Tchou 1948; *Dactylorhizo sacciferae-Juncion striati* Brullo & Grillo, 1978 corr. Bajona 2025

1_1 *Juncus articulatus* community

Relevés Number: TU5_2.

Diagnostic taxa: *Juncus articulatus* L.

Short description: Perennially water-saturated peaty meadow sustained by a shallow water table, dominated by *Juncus articulatus*, with high specific cover-abundance values (>80%), and associated hygrophilous grasses (*Holcus lanatus*, *Poa trivialis*, *Cynosurus cristatus*) and forbs (*Lythrum junceum*, *Galium debile*, *Mentha aquatica*). The occurrence in our communities of *Carex punctata* Gaudin, wich is a typical species of transitional mires, is linked to the presence of peat substrates with low water electrical conductivity (129 µS/cm) and slightly acidic pH (6.05). These communities occur in

close contact with meso-hygrophilous *Cynosurion cristati* grasslands, representing their natural successional stage towards terrestrialization. Such types of succesions have been observed in the transitional mires of Sicily (Raimondo et al. 2021b).

Juncus articulatus is widespread across Europe in a broad variety of wetlands, including coastal saltmarshes, springs, mires, alkaline fens, and fen grasslands (Chytrý et al. 2024).

1_2 *Juncus inflexus* and *Carex otrubae* community

Relevés Number: TU6_1.

Diagnostic taxa: *Juncus inflexus* L., *Carex otrubae* Podp.

Short description: Fen grasslands with summer dryness, dominated by the tall *Juncus inflexus* and *Carex otrubae*, with low cover-abundance values of *Glyceria notata* Chevall. and *Juncus effusus*. *C. otrubae* is an Alliance-characteristic species (Brullo and Grillo 1978), while *J. inflexus* is not only an Holoschoenetalia species but it also occurs in sandy and muddy riverbanks and lakeshores that are periodically flooded, such as the *Galio palustris-Juncetum inflexi* Venanzoni & Gigante, 2000 (*Phragmito-Magnocaricetea*), sometimes forming monospecific stands (Landucci et al. 2013).

Similar communities are distribuited in Sicily, in the Flascio River Valley (Minissale and Spampinato 1985), corresponding to the association *Carici otrubae-Juncetum inflexi* Minissale & Spampinato, 1985 (*Potentillion anserinae* Tx., 1947, *Potentillo-Polygonetalia avicularis* Tx., 1947, *Molinio-Arrhenatheretea* Tx., 1937); the same association has been recorded in the central and northern Apennines (Tardella et al. 2020; Lastrucci et al. 2023).

Our community differs from *Galio palustris-Juncetum inflexi* due to the prevalence of *Molinio-Arrhenatheretea* species and from *Carici otrubae-Juncetum inflexi* because it occurs in close contact with other *Dactylorhizo sacciferae-Juncion striati* communities. It is widespread within the study area and represents the least hygrophilous among rush-dominated communities, often subject to uncontrolled cattle grazing.

1_3 *Galio debilis-Deschampsietum caespitosae* Brullo, Scelsi & Spampinato, 2001

Relevés Number: MI5_4, MI5r_6, MI5_5, MI5r_5.

Diagnostic taxa: *Galium debile* Desv., *Deschampsia cespitosa* (L.) P.Beauv.

Short description: Wet meadows dominated by the tall tufted grass *Deschampsia cespitosa*, which typically densely covers large areas. This species is highly competitive in colonizing the driest peaty meadows, resulting in few constant co-occurring species (*Holcus lanatus*, *Juncus effusus*, *Rumex conglomeratus* Murray, *Bromus hordeaceus*, *Geranium dissectum* L., *Cirsium vulgare* (Savi) Ten.). These communities were found only at MI5, representing the driest stage of succession in *Dactylorhizo sacciferae-Juncion striati* wet meadows (Suppl. material 3: fig. S1A). The constant presence of *Oenanthe fistulosa* is indicative of previous marshy conditions (*Oenantho fistulosae-Glycerietum spicatae* Brullo & Grillo, 1979). The communities show high EC values and near-neutral pH (Fig. 4), growing on soils with higly decomposed organic matter.

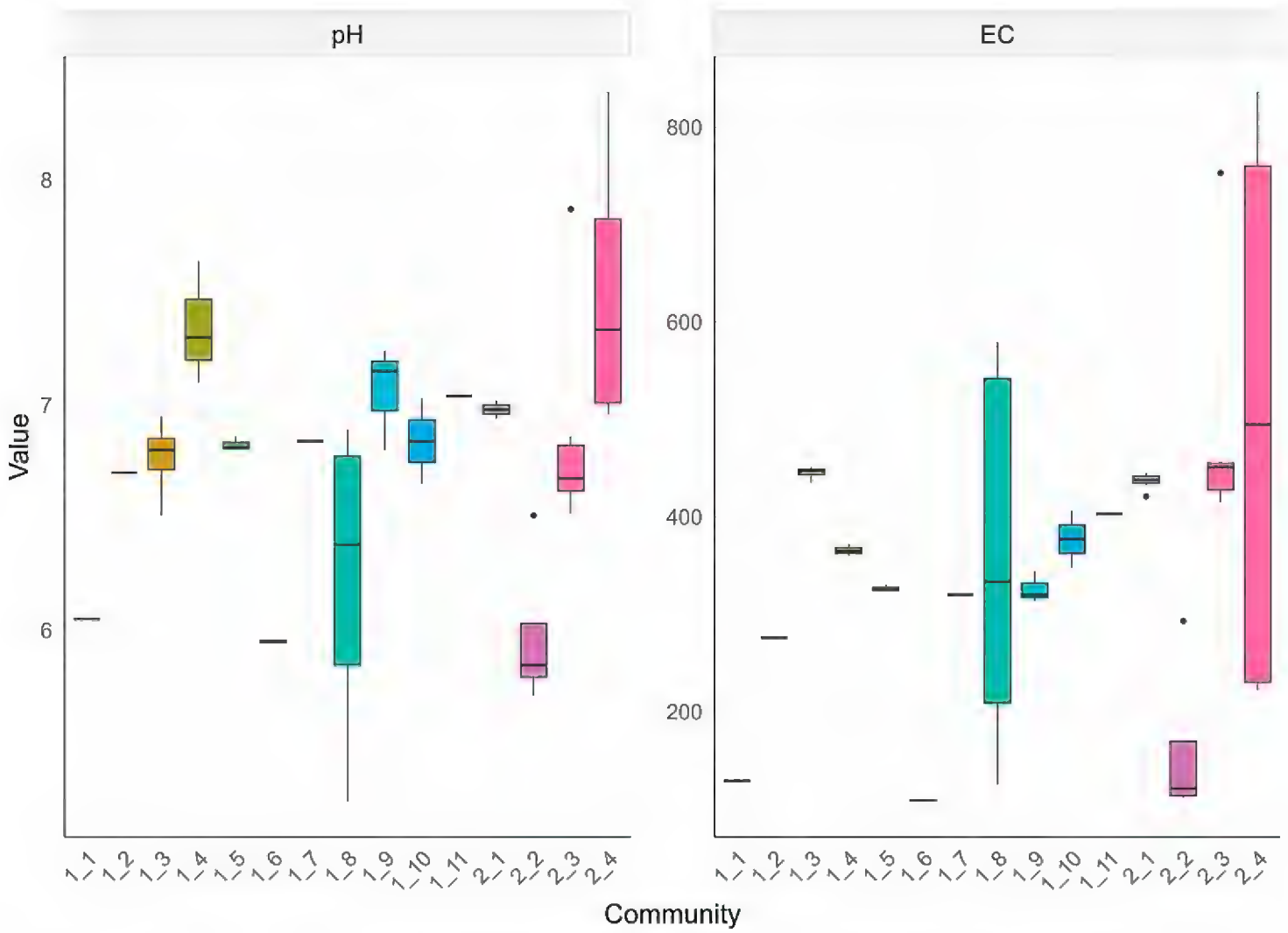

Figure 4. Distribution of hydrochemical variables pH and electrical conductivity (EC, µS/cm) of each community (the numbering of communities corresponds to that of the descriptive overview of plant communities).

Similar *Deschampsia cespitosa*' dominated communities in Italy occur during terrestrialization of other wetland biotopes, including *Sphagnum*-mires (Brancaleoni et al. 2022; Foggi et al. 2007), even on calcareous substrates (*Deschampsio-Caricetum distantis* Pedrotti, 1976).

1_4 *Cyperus longus* and *Juncus articulatus* community

Relevés Number: TU1_1, TU1_2, TU1r_2.

Diagnostic taxa: *Cyperus longus* L., *Juncus articulatus* L., *Polypogon viridis* (Gouan) Breistr., *Lythrum junceum* Banks & Sol.

Short description: Flooded meadows and depressions dominated by *Juncus articulatus* and *Cyperus longus* (Suppl. material 3: fig. S1B). These communities host species typical of *Molinio-Arrhenatheretea* wet meadows and *Phragmito-Magnocaricetea* (*Mentha aquatica*, *Helosciadium nodiflorum*, *Veronica anagallis-aquatica*, *Nasturtium officinale*, *Glyceria notata*), reflecting prolonged groundwater presence. Among GROUP_1 communities, this is the most hygrophilous; it develops on clay-rich substrates with alcaline pH (>7) and high EC values (Fig. 4). Small hummocks with *Isoëto-Nanojuncetea* species (*Isolepis cernua*, *Juncus bufonius*) occur on slightly drier micro-topographies.

Communities characterized by *Cyperus longus* are common in other parts of Italy (Landucci et al. 2013) and in the Balkans (Jasprica and Caric 2002) but are mostly linked to lake and river systems, with a prevalence of *Phragmito-Magnocaricetea* species (*Cyperetum longi* Micevski, 1957).

1_5 *Carex acutiformis* community

Relevés Number: TU4_3, TU4r_3, TU4r_4.

Diagnostic taxa: *Carex acutiformis* Ehrh., *Dactylorhiza maculata* subsp. *saccifera* (Brongn.) Diklić, *Juncus articulatus* L.

Short description: Peaty-clay wet meadows fed by groundwater, water-saturated throughout the growing season, with a poorly developed moss layer. The community is characterized by the tall *Carex acutiformis*, associated with typical species of *Dactylorhizo sacciferae-Juncion striati* wet meadows (*Dactylorhiza maculata* subsp. *saccifera*), order-level species (*Juncus articulatus*, *Lythrum junceum*, *Calliergonella cuspidata*, *Cyperus longus*, *Cirsium creticum* subsp. *triumfetti*), class-level species (*Trifolium repens*, *Poa trivialis*, *Cynosurus cristatus*), and more hygrophilous *Phragmito-Magnocaricetea* species (*Mentha aquatica*, *Helosciadium nodiflorum*), Suppl. material 3: fig. S1C, D. Compared to the *Caricetum acutiformis* Eggler, 1933 (*Magnocaricion elatae* Koch, 1926, *Magnocaricetalia* Pignatti, 1953, *Phragmito-Magnocaricetea* Klika in Klika and Novák 1941), common in Italy from lowlands to sub-montane belts (Landucci et al. 2013), these communities are richer in *Molinio-Arrhenatheretea* species, being in close contact with *Dactylorhizo sacciferae-Juncetum effusi*.

1_6 *Carex punctata* and *Juncus articulatus* community

Relevés Number: TU5_1, TU5r_1.

Diagnostic taxa: *Carex punctata* Gaudin, *Juncus articulatus* L., *Juncus effusus* L.

Short description: Minerogenous peaty spring community, slightly acidic, dominated by *Juncus articulatus*, *Carex punctata*, and *Juncus effusus*, Suppl. material 3: fig. S1E. Associated species mostly belong to *Holoschoenetalia* (*Holcus lanatus*, *Lythrum junceum*, *Calliergonella cuspidata*, *Cyperus longus*, *Cirsium creticum* subsp. *triumfetti*), to the respective class (*Cynosurus cristatus*, *Juncus fontanesii* J.Gay), as well as to *Phragmito-Magnocaricetea* (*Mentha aquatica*, *Glyceria notata*). This community is associated with the lowest EC values (Fig. 4) of the Group, and low pH, reflecting the markedly peaty substrate. Low pH is favoured by organic substrates that have low buffering capacity, with organic matter decomposition producing organic acids.

In other European regions, *Carex punctata* occurs in peaty meadows (*Molinion caeruleae* Koch, 1926) (Delarze et al. 2015).

1_7 *Carex distans* and *Juncus articulatus* community

Relevés Number: TU4_1.

Diagnostic taxa: *Carex distans* L., *Juncus articulatus* L., *Calliergonella cuspidata*, *Isolepis cernua*.

Short description: Community on peaty-clay substrates fed by shallow groundwater. Vegetation is characterized by *Carex distans*, *Juncus articulatus*, and mats of *Calliergonella cuspidata*, Suppl. material 3: fig. S1F. Unlike the previous peaty spring community (1_6), it includes *Isoëto-Nanojuncetea* species (*Isolepis cernua*, *Samolus valerandi* L.) due to higher clay content, and exhibits sub-neutral pH and higher EC (Fig. 4). At TU4, it is in contact to 1.5 *Carex acutiformis* community.

Carex distans is also common in some *Phragmito-Magnocaricetea* communities (Landucci et al. 2013), central-southern Italian humid meadows (*Deschampsio-Caricetum distantis* Pedrotti, 1976; Pedrotti 2019; Tardella et al. 2020), and central European alkaline peatlands (*Caricion davallianae* Klika, 1934; Chytrý et al. 2011).

1_8 *Dactylorhizo sacciferae-Juncetum effusi* Brullo & Grillo, 1978 corr. Bajona 2025

Relevés Number: MI5_3, MI3_1, MI3r_1, MI2_1, MI7_1, MI7_2.

Diagnostic taxa: *Dactylorhiza maculata* subsp. *saccifera* (Brongn.) Diklić, *Juncus effusus* L.

Short description: Peaty meadows physiognomized by *Juncus effusus*, and by *Dactylorhiza maculata* subsp. *saccifera*, during its flowering. Many hygrophilous species of *Holoschoenetalia* (*Juncus articulatus*, *Holcus lanatus*, *Calliergonella cuspidata*, *Galium debile*, *Rumex conglomeratus*) and class-level species (*Trifolium repens*, *Poa trivialis*, *Cynosurus cristatus*, *Bromus hordeaceus*, *Ranunculus sardous* Crantz, *Hypericum tetrapterum* Fr.) occur, with fewer *Phragmito-Magnocaricetea* species (*Mentha aquatica*, *Oenanthe fistulosa*, *Limniris pseudacorus*), Suppl. material 3: fig. S2D. This community is the most acidophilous and associated with low EC values in some stands (MI2_1, MI7_1, MI7_2) but in other plots it is associated with higher pH and EC values (MI5_3, MI3_1, MI3r_1), (Fig. 4). The EC higher value in MI5_3, MI3_1, MI3r_1 is imputable to edaphic factors, since clay-rich substrates of these stands provide good buffering capacity due to the high cation exchange capacity (CEC). These three plots with higher EC differentiate also for the presence of *Oenanthe fistulosa* and *Glyceria spicata*, that are are the diagnostic species of *Oenantho fistulosae-Glycerietum spicatae* Brullo & Grillo, 1978 (*Alopecuro-Glycerion spicatae*), describing temporary mountain pond communities in the Nebrodi (Brullo and Grillo 1979; Brullo et al. 1994). Based on our observations, these communities represent the final stage of pond terrestrialization toward *Dactylorhizo sacciferae-Juncion striati* wet meadows.

The association was first described in the eastern Nebrodi mountains (Brullo and Grillo 1978), later found in Calabria (Aspromonte) (Brullo et al. 2001), sometimes in contact with *Sphagnum*-transitional mires (*Caricion fuscae* Koch, 1926), colonizing drier zones (Brullo et al. 2001; Bajona et al. 2025). It is endemic to southern Italy but ecologically and floristically comparable to other Mediterranean mountain sward communities (mégaphorbiales) (Quézel 1967).

1_9 *Dactylorhizo sacciferae-Juncetum effusi* Brullo & Grillo, 1978 corr. Bajona 2025, *iridetosum pseudacori* Barbagallo, Brullo & Furnari, 1979

Relevés Number: TU4_2, TU2_1, TU2r_1.

Diagnostic taxa: *Limniris pseudacorus* (L.) Fuss, *Dactylorhiza maculata* subsp. *saccifera* (Brongn.) Diklić.

Short description: Community dominated by large tussocks of *Limniris pseudacorus*, with a sparse carpet of *Calliergonella cuspidata*, that settles on peaty substrates fed by shallow groundwater (Suppl. material 3: fig. S3A). Alliance-level species (*Dactylorhiza maculata* subsp. *saccifera*), order-level species (*Cirsium creticum* subsp. *triumfetti*, *Galium debile*), class-level species (*Poa trivialis*, *Cynosurus cristatus*), and, with fewer species, some *Phragmito-Magnocaricetea* (*Mentha aquatica*, *Helosciadium nodiflorum*, *Carex acutiformis*) occur. *Limniris pseudacorus*, a large rhizomatous geophyte, monopolizes space via its rhizomes, limiting competition. At TU4, this community occurs adjacent to 1_5 *Carex acutiformis* community and other *Dactylorhizo sacciferae-Juncion striati* communities, representing a terrestrialization stage, Suppl. material 3: fig. S1C. In fact, the expansion of its large rhizomes and the deposition of the long leaves tend to elevate the surfaces, accelerating spring infilling (Suppl. material 3: fig. S2B). Uncontrolled cattle grazing occurs (Suppl. material 3: fig. S2C).

Similar peaty meadow communities are reported elsewhere in Europe, e.g. English *Holco-Juncetum effusi iridetosum* Page, 1980, but more frequently *Limniris pseudacorus* occurs in marshy biotopes, like marshes, lakes, riverbanks, and swamp shores (*Iridetum pseudacori* Eggler ex Brzeg and Wojterska 2001; Landucci et al. 2013).

1_10 *Glyceria notata* and *Juncus articulatus* community

Relevés Number: TU3_1, MI6_1.

Diagnostic taxa: *Glyceria notata* Chevall., *Juncus articulatus* L.

Short description: Groundwater-fed flooded meadows dominated by *Glyceria notata* (*Phragmito-Magnocaricetea*) and *Juncus articulatus*. Differs from pond communities by the minerogenous water supply, that maintains vegetation cover year-round. Unlike other *Glyceria notata* communities (*Glycerietum notatae* Kulczyński, 1928), it includes *Molinio-Arrhenatheretea* species (*Carex otrubae*, *Juncus articulatus*, *Galium debile*, *Cynosurus cristatus*, *Oenanthe pimpinelloides*). The community in MI6_1 is disturbed by cattle trampling; in fact it is known from scientific literature that *Glyceria notata* is more disturbance-tolerant than *Glyceria fluitans* and other *Glyceria* species (Landucci et al. 2013).

1_11 *Juncus articulatus* and *Veronica anagallis-aquatica* community

Relevés Number: TU1_3.

Diagnostic taxa: *Juncus articulatus* L., *Veronica anagallis-aquatica* L.

Short description: Minerotrophic flooded meadow dominated by *Juncus articulatus* and characterized by *Veronica anagallis-aquatica* (Suppl. material 3: fig. S2E). The presence of many *Phragmito-Magnocaricetea* species, *i.e. Mentha aquatica*, *Helosciadium nodiflorum*, *Nasturtium officinale*, *Glyceria notata*, *Eleocharis palustris* is indicative of the high water saturation of the stands and in accordance with high pH, and EC.

GROUP_2. Phragmito-Magnocaricetea Klika in Klika et Novák 1941; Oenanthetalia aquaticae Hejny ex Balátová-Tuláčková et al. 1993; Alopecuro-Glycerion spicatae S. Brullo et al. 1994

2_1 *Glycerio spicatae-Oenanthetum aquaticae* Brullo, Minissale & Spampinato, 1994

Relevés Number: MI8r_5, MI8_1, MI8r_1, MI8r_9, MI8r_6, MI8r_7, MI8r_8.

Diagnostic taxa: *Glyceria spicata* Guss., *Oenanthe aquatica* (L.) Poir.

Short description: Annual aquatic communities of shallow temporary ponds with silty-clay bottoms. These phytocoenoses are characterized by rooted *Glyceria spicata* carpets dominated by the robust Apiaceae *Oenanthe aquatica*. Vegetation phenology depends on pond seasonality, reaching its complete expression in early summer (Suppl. material 3: fig. S2G). During winter, ponds are covered only by *Glyceria spicata* until late spring (Suppl. material 3: fig. S2F), when *Oenanthe aquatica* starts growing. Vegetation declines and disappears with pond drying, typically from mid to late summer (Suppl. material 3: fig. S2H). Communities occur in neutral water with EC 420–450 µS/cm. In most relevés from the original association description (Brullo et al. 1994), additional species such as *Alopecurus aequalis*, *Peplis portula*, *Potamogeton natans* L., and occasionally *Potamogetonetea* Klika in Klika et Novák 1941 ones, are present, but absent in our communities. Hence, this can be considered a species-impoverished aspect of the association.

Oenanthe aquatica is characteristic of emergent helophyte vegetation on muddy soils of shallow streams and ponds with fluctuating water tables in temperate and boreal Eurasia (*Eleocharito palustris-Sagittarion sagittifoliae* Passarge 1964; Mucina et al. 2016; Lastrucci et al. 2025).

2_2 *Glycerio spicatae-Callitrichetum obtusangulae* subass. *callitrichetosum stagnalis* Brullo, Minissale & Spampinato, 1994

Relevés Number: MI6_2, MI2_2, TU5_3, TU5r_3.

Diagnostic taxa: *Callitriche stagnalis* Scop., *Ranunculus omiophyllus* Ten.

Short description: Communities of small pools with peaty (MI2_2, TU5_3, TU5r_3) or silty (MI6_2) substrates fed by groundwater, with water persisting almost year-round. Communities develope on pools located at spring margins, often shaded by forest or shrub edges (Suppl. material 3: fig. S3B). Their composition is dominated by hydrophytes like *Callitriche stagnalis*, typically forming floating mats, associated with *Ranunculus omiophyllus*. Other community-forming species include *Glyceria*

spicata, *Peplis portula* (*Alopecuro-Glycerion spicatae*), *Glyceria notata*, *Mentha aquatica*, *Helosciadium nodiflorum* (*Phragmito-Magnocaricetea*). Marginal areas drying early host *Juncus bufonius* (*Isoeto-Nanojuncetaea*). pH is slightly acidic in most plots, EC <130 µS/cm, except MI6_2 with sub-neutral pH and higher EC due to silty substrate.

These communities have been assigned to subass. *callitrichetosum stagnalis* of *Glycerio spicatae-Callitrichetum obtusangulae* based on floristic and ecological similarity. This community differs from the nominal subassociation by higher *Callitriche stagnalis* cover-abundance, favored by shady site conditions (Brullo et al. 1994). Similar, more heliophilous communities were recently described in NW Sicily ("*Callitriche stagnalis* community" belonging to *Ranunculion aquatilis* alliance, Caldarella et al. 2021).

2_3 *Eleocharis palustris* and *Oenanthe fistulosa* community

Relevés Number: MI5_2, MI5_1, MI1_2, MI8_3, MI8_4, MI8_2.

Diagnostic taxa: *Eleocharis palustris* (L.) Roem. & Schult., *Oenanthe fistulosa* L., *Glyceria spicata* Guss.

Short description: Communities dominated by *Eleocharis palustris* with constant but low *Oenanthe fistulosa* cover-abundance (Suppl. material 3: fig. S3E). Communities occur in the flooded shores of temporary ponds with silty bottoms, or in the depressions of wet meadows derived from pond terrestrialization. In more terrestrialized stations, *Holoschoenetalia* species (*Juncus effusus*, *Galium debile*, *Rumex conglomeratus*) join the community; in more flooded sites, rooted hydrophytes (*Helosciadium inundatum*, *Ranunculus peltatus*) occur with *Glyceria spicata*. Some *Isoeto-Nanojuncetaea* species (*Ranunculus muricatus*, *Mentha pulegium*) indicate summer desiccation. Terrestrialization often leads to evolution of these communities toward *Juncus effusus* swards, or *Galio debilis-Deschampsietum caespitosae*' humid meadows as occurs in MI5 (Suppl. material 3: fig. S3D, E). The communities are associated with sub-neutral to basic pH and high EC (Fig. 4).

Similar communities are also found in other Mediterranean areas, like in Spain (Mercadal et al. 2008), where *Oenanthe fistulosa* characterizes the vegetation of temporary ponds and wet meadows of Catalogna (*Baldellio ranunculoidis-Oenanthetum fistulosae* Mercadal, Gesti & Vilar, 2008) and in France, where *Oenanthe fistulosa* is frequent in temporary wet mown meadows on mineral soils (*Bromion racemosi* Tx. in Tx. and Preising ex de Foucault 2009; Bournérias et al. 2002).

2_4 *Helosciadium inundatum* and *Glyceria notata* community

Relevés Number: MI1r_1, MI1_1, MI1_3, MI4r_1, MI4_1, MI4r_2.

Diagnostic taxa: *Helosciadium inundatum* (L.) W.D.J.Koch, *Glyceria notata* Chevall.

Short description: Temporary pond communities with constant presence of *Helosciadium inundatum* and *Glyceria notata* (Suppl. material 3: fig. S3C, F–H). In MI_4 pond (Suppl. material 3: fig. S3C), *Glyceria notata* dominates with dense mats;

conversely in deeper MI_1 (Suppl. material 3: fig. S3H), *Helosciadium inundatum* surpasses *Glyceria notata*. Furthermore, *Ranunculus peltatus* forms dense mats in some patches of MI_1 pond.

The two ponds MI_1 and MI_4 differ also in hydrochemistry: while MI_1 is alkaline with EC >750 µS/cm, MI_4 is neutral with EC <232 µS/cm. These hydrochemical differences are possibly due to a higher presence of cattle in MI_1, which causes eutrophication.

Both *Helosciadium inundatum* and *Ranunculus peltatus* are high-frequency species in the original *Oenantho fistulosae-Glycerietum spicate*' relevés (Brullo and Grillo 1978); for this reason, this community is considered a species-impoverished form of this association.

Syntaxonomical scheme

Molinio-Arrhenatheretea Tx. 1937
Holoschoenetalia Br.-Bl. ex Tchou 1948
Dactylorhizo sacciferae-Juncion striati Brullo & Grillo, 1978 corr. Bajona 2025
Juncus articulatus community
Juncus inflexus and *Carex otrubae* community
Galio debilis-Deschampsietum caespitosae Brullo, Scelsi & Spampinato, 2001
Cyperus longus and *Juncus articulatus* community
Carex acutiformis community
Carex punctata and *Juncus articulatus* community
Carex distans and *Juncus articulatus* community
Dactylorhizo sacciferae-Juncetum effusi Brullo & Grillo, 1978 corr. Bajona 2025
Dactylorhizo sacciferae-Juncetum effusi Brullo & Grillo, 1978 corr. Bajona 2025 subass. *iridetosum pseudacori* Barbagallo, Brullo & Furnari, 1979
Glyceria notata and *Juncus articulatus* community
Juncus articulatus and *Veronica anagallis-aquatica* community

Phragmito-Magnocaricetea Klika in Klika et Novak 1941
Oenanthetalia Aquaticae Hejny ex Balatova-Tulackova et al. 1993
Alopecuro-Glycerion spicatae S. Brullo et al. 1994
Glycerio spicatae-Oenanthetum aquaticae Brullo, Minissale & Spampinato, 1994
Glycerio spicatae-Callitrichetum obtusangulae subass. *callitrichetosum stagnalis* Brullo, Minissale & Spampinato, 1994
Eleocharis palustris and *Oenanthe fistulosa* community
Helosciadium inundatum and *Glyceria notata* community

Conclusions

The approach adopted in this vegetation survey, with the application of small plot size (1 m^2), has the advantage of capturing in detail the microcenotic variability of the communities and their relationships with abiotic parameters. Through this meth-

od, it was possible to characterize 10 new communities, three associations, and two sub-associations. As already discussed, some of these communities represent dynamic stages of certain associations, differing from them not only in floristic composition but also in micromorphological features. Nevertheless, in such cases, no syntaxonomic rank at the association level was assigned. In order to deepen knowledge of these communities, future investigations in similar ecological contexts of the Sicilian and southern Italian mountains are needed. Furthermore, small plots are not always suitable for describing new plant community associations, especially those dominated by tall sedges or rushs.

The new communities described here are often characterized by broad-distribution species, already reported in known plant assemblages of other types of wetland biotopes, such as *Helosciadium inundatum*, *Glyceria notata*, *Juncus articulatus*, *Eleocharis palustris*, *Oenanthe fistulosa*, *Limniris pseudacorus*, *J. effusus*, *J. inflexus*, *Cyperus longus*, and *Carex acutiformis*. However, these communities are newly documented within the ecological contexts investigated, *i.e.* the wet meadows, springs, and peaty springs characterized by species of the *Dactylorhizo sacciferae-Juncion striati* Brullo & Grillo, 1978 corr. Bajona 2025, as well as temporary ponds of the *Alopecuro-Glycerion spicatae* S. Brullo et al., 1994. Their description widens the current range of the two alliances. In particular, *Dactylorhizo sacciferae–Juncion striati* is here reported from the western area of the Nebrodi and the Madonie mountains, while *Alopecuro-Glycerion spicatae* is newly recorded from the western are of the Nebrodi. Until now, the distribution of *Dactylorhizo sacciferae-Juncion striati* was restricted to the eastern Nebrodi in Sicily, as well as the Aspromonte and Serre Calabre massifs in Calabria, whereas *Alopecuro-Glycerion spicatae* was only known from its originally described stations in the eastern Nebrodi.

The occurrence of such type of wetlands in the Sicilian mountain landscape not only ensures the conservation of aquatic plant species but also provides essential refugia for microalgal communities, amphibians, and associated terrestrial vertebrates.

The inventory of the wetland sites reported here provides useful information for public administrations to implement targeted regulations of human activities exploiting natural resources, in a perspective of biodiversity conservation. The georeferenced floristic data are a potential data source for biodiversity databases (Fois et al. 2022). Indeed, some of these sites are threatened by anthropogenic pressures, including water subtraction and uncontrolled grazing. In the case of grazing, the release of livestock urine into temporary ponds can increase water salinity, particularly in the investigated ponds where limited volume reduces water mixing. Furthermore, trampling by cattle in springs, peatlands, and wet meadows causes physical damage, disrupts surface hydrology, and promotes eutrophication. Such pressures facilitate the invasion of nitrophilous species into plant communities, leading to floristic homogenization and the acceleration of successional processes that result in wetland infilling.

In conclusion, this survey demonstrates that field investigations finalized to the collection of information on vegetation, flora, and environmental features is crucial for the conservation of wetland habitats.

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Supplementary material 1

"Structured table of plant communities"

Authors: Enrico Bajona, Francesco Maria Raimondo, Emilio Di Gristina, Giannantonio Domina, Raimondo Pardi, Fortunato Cirlincione

Data type: xlsx

Explanation note: It includes all the vegetation relevés (with relative geographic coordinates and abiotic data reported) structured according syntaxonomic interpretation of cluster analysis.

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Link: https://doi.org/10.3897/italianbotanist.21.171191.suppl1

Supplementary material 2

"Cluster dendrogram of the species × relevés matrix"

Authors: Enrico Bajona, Francesco Maria Raimondo, Emilio Di Gristina, Giannantonio Domina, Raimondo Pardi, Fortunato Cirlincione

Data type: jpeg

Explanation note: Dendrogram obtained by Cluster analysis, the sub-clusters number corresponds to communities/associations labels.

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Link: https://doi.org/10.3897/italianbotanist.21.171191.suppl2

Supplementary material 3

"Figures of plant communities"

Authors: Enrico Bajona, Francesco Maria Raimondo, Emilio Di Gristina, Giannantonio Domina, Raimondo Pardi, Fortunato Cirlincione

Data type: pdf

Explanation note: It includes a selection of photos of the plant communities and sites surveyed. **fig. S1. A.** Galio debilis-Deschampsietum caespitosae' humid meadow in MI5; **B.** Cyperus longus and Juncus articulatus community; **C-D.** Carex acutiformis community in TU4 in contact with Dactylorhizo sacciferae-Juncetum effusi subass. iridetosum pseudacori; **E.** Carex punctata and Juncus articulatus community with a focus on C. punctata; **F.** Carex distans and Juncus articulatus community. **fig. S2. A.** Oenanthe fistulosa and Juncus effusus community; **B.** winter aspect (05/02/2022) of the Dactylorhizo sacciferae-Juncetum effusi subass. iridetosum pseudacori: the expansion of Limniris pseudacorus tend to elevate the surface, accelerating the peat bog' infilling; **C.** uncontrolled cattle grazing in TU4; **D.** Dactylorhizo sacciferae-Juncetum effusi; **E.** Juncus articulatus and Veronica anagallis-aquatica community; **F.** late spring (14/05/2025), **G.** mid summer (04/07/2025) and **H.** late summer Glycerio spicatae-Oenanthetum aquaticae' phenology in MI8 temporary pond. **fig. S3. A.** Dactylorhizo sacciferae-Juncetum effusi subass. iridetosum pseudacori; **B.** shady pool characterized by Glycerio spicatae-Callitrichetum obtusangulae subass. callitrichetosum stagnalis; **C.** Helosciadium inundatum and Glyceria notata community in MI1; **D-E.** Eleocharis palustris and Oenanthe fistulosa community in conctact with Juncus effusus swards (**D**) and Galio debilis-Deschampsietum caespitosae' humid meadows (**E**); **F.** early summer (07/06/2025) and **G.** late summer (18/08/2025) aspect of MI1' temporary pond; **H.** Helosciadium inundatum and Glyceria notata community in MI4 temporary pond.

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